

## Decompressive Craniectomy versus Craniotomy for Acute Subdural Hematoma

P.J. Hutchinson, H. Adams, M. Mohan, B.I. Devi, C. Uff, S. Hasan, H. Mee, M.H. Wilson, D.K. Gupta, D. Bulters, A. Zolnourian, C.J. McMahon, M.G. Stovell, Y.Z. Al-Tamimi, M.K. Tewari, M. Tripathi, S. Thomson, E. Viaroli, A. Belli, A.T. King, A.E. Helmy, I.S. Timofeev, S. Pyne, D.P. Shukla, D.I. Bhat, A.R. Maas, F. Servadei, G.T. Manley, G. Barton, C. Turner, D.K. Menon, B. Gregson, and A.G. Koliass, for the British Neurosurgical Trainee Research Collaborative, NIHR Global Health Research Group on Acquired Brain and Spine Injury, and RESCUE-ASDH Trial Collaborators\*

### ABSTRACT

#### BACKGROUND

Traumatic acute subdural hematomas frequently warrant surgical evacuation by means of a craniotomy (bone flap replaced) or decompressive craniectomy (bone flap not replaced). Craniectomy may prevent intracranial hypertension, but whether it is associated with better outcomes is unclear.

#### METHODS

We conducted a trial in which patients undergoing surgery for traumatic acute subdural hematoma were randomly assigned to undergo craniotomy or decompressive craniectomy. An inclusion criterion was a bone flap with an anteroposterior diameter of 11 cm or more. The primary outcome was the rating on the Extended Glasgow Outcome Scale (GOSE) (an 8-point scale, ranging from death to “upper good recovery” [no injury-related problems]) at 12 months. Secondary outcomes included the GOSE rating at 6 months and quality of life as assessed by the EuroQol Group 5-Dimension 5-Level questionnaire (EQ-5D-5L).

#### RESULTS

A total of 228 patients were assigned to the craniotomy group and 222 to the decompressive craniectomy group. The median diameter of the bone flap was 13 cm (interquartile range, 12 to 14) in both groups. The common odds ratio for the differences across GOSE ratings at 12 months was 0.85 (95% confidence interval, 0.60 to 1.18;  $P=0.32$ ). Results were similar at 6 months. At 12 months, death had occurred in 30.2% of the patients in the craniotomy group and in 32.2% of those in the craniectomy group; a vegetative state occurred in 2.3% and 2.8%, respectively, and a lower or upper good recovery occurred in 25.6% and 19.9%. EQ-5D-5L scores were similar in the two groups at 12 months. Additional cranial surgery within 2 weeks after randomization was performed in 14.6% of the craniotomy group and in 6.9% of the craniectomy group. Wound complications occurred in 3.9% of the craniotomy group and in 12.2% of the craniectomy group.

#### CONCLUSIONS

Among patients with traumatic acute subdural hematoma who underwent craniotomy or decompressive craniectomy, disability and quality-of-life outcomes were similar with the two approaches. Additional surgery was performed in a higher proportion of the craniotomy group, but more wound complications occurred in the craniectomy group. (Funded by the National Institute for Health and Care Research; RESCUE-ASDH ISRCTN Registry number, ISRCTN87370545.)

The authors' full names, academic degrees, and affiliations are listed in the Appendix. Dr. Hutchinson can be contacted at [pjah2@cam.ac.uk](mailto:pjah2@cam.ac.uk) or at the Division of Neurosurgery, Box 167, University of Cambridge, Cambridge Biomedical Campus, Cambridge CB2 0QQ, United Kingdom.

\*A complete list of the investigators and members of the trial oversight committees is provided in the Supplementary Appendix, available at [NEJM.org](http://NEJM.org).

This article was published on April 23, 2023, at [NEJM.org](http://NEJM.org).

N Engl J Med 2023;388:2219-29.

DOI: 10.1056/NEJMoa2214172

Copyright © 2023 Massachusetts Medical Society.

**CME**  
at [NEJM.org](http://NEJM.org)



A Quick Take  
is available at  
NEJM.org

**D**ECOMPRESSIVE CRANIECTOMY IS A surgical procedure in which a large skull section is removed, and the underlying dura mater is opened widely.<sup>1</sup> The procedure has been shown to reduce mortality when used as a last-tier treatment for post-traumatic intracranial hypertension<sup>2</sup> but is associated with a higher risk of unfavorable outcomes<sup>3</sup> when used as a second-tier treatment. However, the most common indication for a decompressive craniectomy is a traumatic subdural hematoma.<sup>4-7</sup>

Because acute subdural hematomas are often associated with underlying parenchymal brain injury, brain swelling can be encountered intraoperatively or postoperatively.<sup>8,9</sup> Therefore, a primary decompressive craniectomy is often performed at the time of evacuating an acute subdural hematoma, either because of brain swelling that does not allow replacement of the bone flap without compression of the brain or preemptively in anticipation of swelling in the ensuing days based on clinician judgment.<sup>10</sup> In the former situation, the bone flap must be left out. However, there is limited evidence with respect to the added value of performing a decompressive craniectomy preemptively in this context.<sup>11</sup> The effectiveness of a primary decompressive craniectomy (bone flap left out) as compared with a craniotomy (bone flap replaced) for evacuation of acute subdural hematomas has not been adequately studied. It is important to address this choice in a trial, particularly because craniectomy necessitates a subsequent operation for reconstructing the skull (termed cranioplasty) that has risks.<sup>12</sup> We conducted a multicenter, randomized, controlled trial to compare the outcomes of craniotomy and decompressive craniectomy in adult patients with traumatic acute subdural hematoma.

## METHODS

### TRIAL DESIGN AND OVERSIGHT

The RESCUE-ASDH (Randomized Evaluation of Surgery with Craniectomy for Patients Undergoing Evacuation of Acute Subdural Hematoma) trial was an investigator-initiated, international, multicenter, pragmatic, randomized trial involving adult patients with head injury who were undergoing evacuation of an acute subdural hematoma. Ethical approval was obtained from the North West–Haydock Research Ethics Commit-

tee in the United Kingdom and ethics committees in the participating countries. The funder was the National Institute for Health and Care Research Health Technology Assessment Programme, which had no involvement in the design of the trial or the analysis of the data but required approval of substantial changes to the trial design (see below). The trial protocol (available with the full text of this article at NEJM.org) was designed by a team of neurosurgeons, intensivists, and methodologists from several hospitals and universities worldwide; the team was led by the first and last authors. The analysis was conducted by the penultimate author, who is the trial statistician.

An internal pilot phase, which enrolled 92 patients at 19 trial sites, confirmed the feasibility of the overall trial. The pilot phase did not aim to assess efficacy or reestimate the overall sample size. These 92 patients were included in the final analysis of the current trial.

We anticipated that most patients would lack the capacity to provide consent for participation in the trial. When possible, written informed consent was obtained from the patient's legal representative. Owing to the time-sensitive nature of evacuating acute subdural hematomas, patients whose legal representative was not available could be enrolled in the trial with the agreement of an independent physician. When a legal representative became available, their consent was sought retrospectively. When patients regained capacity, their retrospective consent was also sought. An independent trial steering committee and an independent data monitoring and ethics committee reviewed the trial every 6 to 12 months to assess conduct, progress, and safety. The Cambridge Clinical Trials Unit provided methodologic input to protocol design. The trial was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice guidelines, and the investigators vouch for the accuracy and completeness of the data, the fidelity of the trial to the protocol and the statistical analysis plan (available with the protocol), and the full reporting of adverse events.

### PATIENTS

To be eligible for enrollment, patients had to be older than 16 years of age and have an acute subdural hematoma on a computed tomographic (CT) scan of the head that warranted evacuation

with a large bone flap by either a craniotomy or a decompressive craniectomy according to the opinion of the admitting neurosurgeon. Eligibility for enrollment was not restricted in terms of the time from injury or development of a subdural hematoma. Patients with additional cerebral lesions (e.g., intracerebral hematoma or contusions) could be included. Patients with bilateral acute subdural hematomas, each warranting evacuation, or with severe preexisting disability or severe illness that would lead to a poor outcome even if the patient made a full recovery from the head injury were excluded from trial participation. Trial sites were hospitals with acute neurosurgical services for patients with traumatic brain injury (see the Supplementary Appendix, available at NEJM.org).

#### TREATMENT AND RANDOMIZATION

Enrolled patients underwent evacuation of the acute subdural hematoma in the operating room while under general anesthesia. In both trial groups, a bone flap of a recommended size of 11 cm or more in anteroposterior diameter ipsilateral to the hematoma was raised, the dura opened, and the hematoma evacuated. Other lesions, such as intracerebral hematoma or contusions, could be evacuated at the surgeon's discretion. After the subdural hematoma was evacuated, patients were randomly assigned to a trial group in the operating room with the use of a central telephone or Web-based randomization service. The process of randomization took place intraoperatively. If the brain was too swollen to allow replacement of the bone flap without it being compressed, the bone flap was left out and the patient did not undergo randomization.

Block randomization was used, with a block size of 4 and a trial-group assignment ratio of 1:1; patients were assigned randomly within each block. Randomization was stratified according to geographic region, age group, severity of injury, and CT findings (see the protocol for further details). Patients in the craniotomy group could undergo a decompressive craniectomy at a later time at the discretion of their treating clinician if their condition deteriorated after their index procedure. Patients, relatives, and treating physicians were aware of the trial-group assignments because the skull defect is noticeable until a cranioplasty is undertaken. However,

outcomes were adjudicated centrally by investigators who were unaware of the trial-group assignments.

Patients who were assigned to undergo craniotomy had their bone flap replaced and fixed to the surrounding skull with an appropriate fixation system before scalp closure. Patients who were assigned to undergo decompressive craniectomy had their dura left open or there was a nonconstricting duraplasty before scalp closure, and their bone flap was left out. The type of the incision, method used to close the dura in the craniotomy group, use of wound drains and intracranial-pressure monitors, and method for scalp closure were left to the discretion of the surgeons. At U.K. sites, most reconstructions of the craniectomy were later done with titanium or synthetic materials; in India, most cranioplasty replacements were later performed from the autologous bone flap with storage of the flap in the abdominal wall. Management of patient care before, during, and after surgery was undertaken according to the standard practice at each center for patients with head injuries.

#### OUTCOMES

The primary outcome was the rating on the Extended Glasgow Outcome Scale (GOSE) at 12 months after injury. The GOSE is an ordinal outcome scale assessing functional independence, work, social and leisure activities, and personal relationships.<sup>13</sup> Its eight outcome categories are as follows: death, vegetative state (unable to obey commands), lower severe disability (dependent on others for care), upper severe disability (independent at home), lower moderate disability (independent at home and outside the home but with some physical or mental disability), upper moderate disability (independent at home and outside the home but with some physical or mental disability, with less disruption than lower moderate disability), lower good recovery (able to resume normal activities with some injury-related problems), and upper good recovery (no injury-related problems).

Postal questionnaires were used to follow up with surviving patients and were collated centrally by the Cambridge Clinical Trials Unit.<sup>14</sup> If no response was received, a member of the research team contacted the patient or a caregiver by telephone to complete the questionnaire. Outcomes were centrally adjudicated on the basis

of GOSE questionnaires by two trial team investigators who were unaware of the trial-group assignments and who made adjudications independently of each other according to a standardized approach. Disagreements were resolved by consensus between them or with the consultation of a third trial team investigator who was also unaware of the trial-group assignments.

There were 12 secondary outcomes: the GOSE rating at 6 months after injury; the EuroQol Group 5-Dimension 5-Level questionnaire (EQ-5D-5L) utility index score at discharge and at 6 months and 12 months after randomization (responses on the EQ-5D-5L were converted into a utility index score with the use of the cross-walk algorithm; scores range from  $-0.594$  [health state worse than death] to 1 [perfect health state], and patients who died were given a score of zero)<sup>15,16</sup>; Glasgow Coma Scale (GCS) score on discharge from the intensive care unit (ICU) and from the neurosurgical unit; length of stay in the ICU, neurosurgical unit, and rehabilitation unit; score on the Therapy Intensity Level scale for control of intracranial pressure (scores were assessed on a daily basis during the ICU stay after randomization and include 0 [no specific intracranial pressure-directed therapy], 1 [basic ICU care], 2 [mild], 3 [moderate], and 4 [extreme])<sup>17</sup>; discharge destination from neurosurgical unit; death at 30 days, 6 months, and 12 months after injury; serious adverse events and surgical complications during index admission; further cranial surgery within 2 weeks after randomization; subsequent readmissions to the neurosurgical unit within the 12-month follow-up period for a cranioplasty; hydrocephalus resulting in shunt insertion within the 12-month follow-up period; and economic evaluation. The results of the economic evaluation have not been analyzed.

#### STATISTICAL ANALYSIS

A formal sample-size calculation was performed with the use of a Wilcoxon–Mann–Whitney rank-sum test for ordered categories (nQuery Advisor, version 7.0). We estimated that a sample of 990 patients in an ordinal analysis would allow us to detect the equivalent of an absolute difference of 8 percentage points in the percentage of participants with a favorable outcome (defined as upper severe disability or better on the GOSE) at 12 months after randomization (35% in the craniotomy group vs. 43% in the

decompressive craniectomy group; number needed to treat, 12.5) with 90% power at the 5% significance level (two-sided), with allowance for a loss to follow-up of up to 10%. The 8-percentage-point difference was determined to be a clinically relevant treatment effect on the basis of estimates of a favorable outcome in 35% of patients in previous studies.<sup>9,18</sup> Owing to previous work by the IMPACT (International Mission for Prognosis and Analysis of Clinical Trials in TBI) Project, it was decided that the primary analysis of the GOSE ratings should use an ordinal approach based on proportional-odds methods.<sup>19</sup>

However, after the trial started, many participating surgeons expressed the view that a larger treatment effect would be required to encourage them to change their practice, especially since the “experimental” intervention in question (i.e., craniectomy) necessitates a second operation (i.e., cranioplasty). Thus, it became clear that a number needed to treat of 12.5 with its corresponding sample size of 990 may not be appropriate. To address this matter, a survey among 28 principal investigators who were neurosurgeons with expertise in neurotrauma was undertaken over a period of several months, during which approximately 200 patients had been enrolled and had undergone randomization but before unblinding of any outcome data. The survey showed that the mean number needed to treat that would lead these surgeons to change their practice was 7, which is equivalent to a between-group difference of 14 percentage points in the percentage of participants with a favorable outcome. Thus, the sample size was reestimated in 2018 with the use of a 14-percentage-point treatment effect, yielding an updated sample size of 440, with allowance for a 10% loss to follow-up. A sample size of 440 would provide the trial with more than 90% power to detect a between-group difference of 14 percentage points in an ordinal analysis and more than 80% power to detect a difference of 14 percentage points in a binary analysis. This change was discussed with and approved by the independent trial steering committee, independent data monitoring and ethics committee, and trial funder.

Outcome analyses were performed in the modified intention-to-treat population, which included all randomly assigned patients except

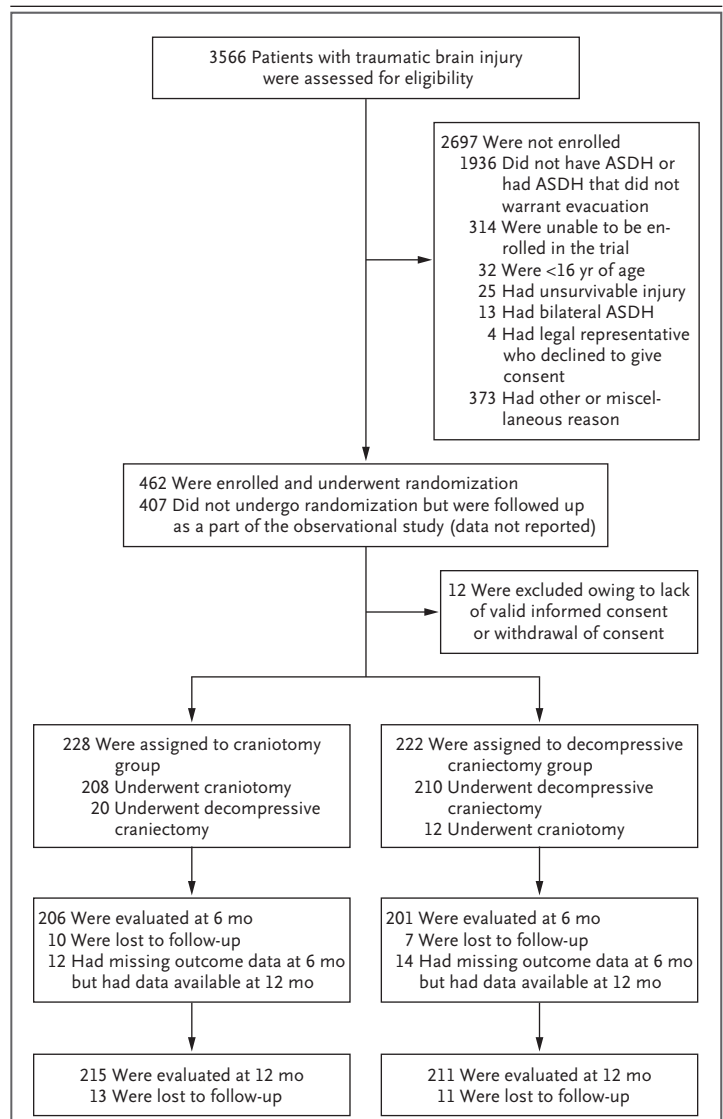
those who withdrew consent for participation in the trial and those lost to follow-up. Patients were retained for analyses in the group to which they were originally assigned, regardless of protocol adherence. The main analysis was undertaken as an ordinal analysis based on the proportional-odds model, with the results presented as the estimated common odds ratio with its corresponding 95% confidence interval and P value. The common odds ratio measured the likelihood that craniotomy would lead to worse GOSE ratings than decompressive craniectomy. The goodness of fit of the unadjusted proportional-odds model was tested, and the assumptions of the model were met. Further prespecified secondary analyses were planned, including a fixed dichotomy analysis and a sliding dichotomy. The former compared the proportion of patients having an “unfavorable” outcome (defined as death, vegetative state, or lower severe disability on the GOSE) between the two groups with the use of the chi-square test. The latter used a sliding dichotomy to define an unfavorable outcome; if the GCS score at randomization was 3 to 8, an unfavorable GOSE outcome was defined as lower severe disability or worse, but if the GCS score at randomization was 9 to 15, an unfavorable GOSE outcome was defined as upper severe disability or worse.

There was no prespecified plan for imputation of missing data, but we performed a post hoc analysis of the two groups with respect to death, vegetative state, and lower severe disability as compared with the better outcome grades, under the assumption that patients lost to follow-up with an initial GCS score of 9 or more had a favorable outcome and those with a GCS score of 8 or less had an unfavorable outcome. Because there was no prespecified plan for adjustment of the widths of confidence intervals for secondary-outcome comparison, no definite conclusions can be drawn from these results. Details are provided in the statistical analysis plan.

## RESULTS

### PATIENTS

Patients were enrolled in the trial from September 2014 through April 2019 at 40 centers in 11 countries (United Kingdom, India, Canada, Malaysia, Germany, Spain, United States, Australia, Hungary, Pakistan, and Singapore). A total of



**Figure 1. Screening, Randomization, and Follow-up.**

Of the 20 patients who were assigned to the craniotomy group but underwent decompressive craniectomy, the main reason for nonadherence was intraoperative brain swelling. Of the 12 patients who were assigned to the decompressive craniectomy group but underwent craniotomy, the main reason for nonadherence was a “relaxed” brain (i.e., slack brain with no swelling). Of the 10 patients in the craniotomy group who were lost to follow-up at 6 months, 8 were known to be alive. Of the 7 patients in the decompressive craniectomy group who were lost to follow-up at 6 months, 5 were known to be alive. Of the 13 patients in the craniotomy group who were lost to follow-up at 12 months, 9 were known to be alive. Of the 11 patients in the decompressive craniectomy group who were lost to follow-up at 12 months, 9 were known to be alive. ASDH denotes acute subdural hematoma.

3566 patients were screened for eligibility, and 462 were enrolled. Twelve patients were withdrawn owing to a lack of valid informed consent

**Table 1. Characteristics of the Patients at Baseline.\***

Characteristic	Craniotomy (N=228)	Decompressive Craniectomy (N=222)
Age — yr	48.3±16.5	48.8±16.6
Male sex — no. (%)	178 (78.1)	179 (80.6)
Race or ethnic group — no./total no. (%)†		
White	117/227 (51.5)	117/219 (53.4)
Asian and Southeast Asian	100/227 (44.1)	90/219 (41.1)
Black	4/227 (1.8)	4/219 (1.8)
Other	6/227 (2.6)	8/219 (3.7)
Any antithrombotic medication — no./total no. (%)‡	30/209 (14.4)	31/202 (15.3)
Major noncranial injury resulting in admission — no./total no. (%)	90/225 (40.0)	83/220 (37.7)
Score on Glasgow Coma Scale of 3–8 — no. (%)§	148 (64.9)	146 (65.8)
Initial findings on CT of the brain — no./total no. (%)		
Presence of midline shift >5 mm	195/226 (86.3)	189/221 (85.5)
Compression or absence of basal cisterns	197/226 (87.2)	192/221 (86.9)
Presence of parenchymal contusions ≤25 ml	109/227 (48.0)	104/221 (47.1)

\* Plus–minus values are means ±SD.

† Data on race and ethnic group were obtained from medical records or reported by the patient's legal representative.

The distribution of race and ethnic group across countries was similar in the two groups.

‡ Medications include antiplatelet agents and anticoagulants.

§ Scores on the Glasgow Coma Scale range from 3 to 15, with lower scores indicating a worse injury. The median score was 8 (interquartile range, 4 to 11) in the craniotomy group and 7.5 (interquartile range, 6 to 11) in the decompressive craniectomy group.

or withdrawal of consent. This resulted in a total of 228 patients in the craniotomy group and 222 in the decompressive craniectomy group. Of 228 patients in the craniotomy group, 208 underwent a craniotomy and 20 underwent a decompressive craniectomy but were included in their original assignment group. Of 222 patients in the decompressive craniectomy group, 210 underwent a decompressive craniectomy and 12 underwent a craniotomy but were included in their original assignment group. The primary outcome was assessed in 426 patients (215 in the craniotomy group and 211 in the decompressive craniectomy group) (Fig. 1).

The characteristics of the patients at baseline were similar in the two groups (Table 1). Severity of brain injury as assessed by GCS scores, pupil reactivity, mechanism of injury, presence of major noncranial injury, and medical history was similar in the two groups. Approximately 15% of the patients in both groups had been receiving anticoagulant or antiplatelet medications. Approximately 65% had a GCS score of 3 to 8 at baseline. Findings on CT of the head at

baseline were also similar in the two groups; 56.1% of patients in the craniotomy group had an acute subdural hematoma located over the right hemisphere, and 53.6% of patients in the decompressive craniectomy group had a hematoma located over the left hemisphere. The median size of the bone flap was 13 cm (interquartile range, 12 to 14) in both groups (Table S6 in the Supplementary Appendix). The representativeness of the trial population is shown in Table S17. Approximately 2% of the patients in both trial groups were Black.

#### PRIMARY OUTCOME

In the modified intention-to-treat ordinal analysis of GOSE ratings at 12 months, the common odds ratio across outcome categories for the craniotomy group as compared with the decompressive craniectomy group was 0.85 (95% confidence interval [CI], 0.60 to 1.18;  $P=0.32$ ) (Table 2 and Fig. 2). The GOSE distributions were as follows: death, 30.2% among 215 patients in the craniotomy group and 32.2% among 211 patients in the decompressive craniectomy group;

vegetative state, 2.3% and 2.8%, respectively; lower severe disability (dependent on others for care), 17.7% and 19.4%; upper severe disability (independent at home), 13.0% and 12.8%; moderate disability, 11.2% and 12.8%; and good recovery, 25.6% and 19.9%.

In the prespecified secondary fixed-dichotomy analysis, unfavorable outcomes at 12 months (defined as death, vegetative state, or lower severe disability on the GOSE) were reported in 108 of 215 patients (50.2%) in the craniotomy group and in 115 of 211 (54.5%) in the decompressive craniectomy group (odds ratio, 0.84; 95% CI, 0.58 to 1.23). In the sliding-dichotomy analysis, the odds ratio for unfavorable outcomes with craniotomy was 0.77 (95% CI, 0.53 to 1.14). Covariate adjustment of the ordinal analysis produced results similar to those of the unadjusted ordinal analysis (common odds ratio, 0.84; 95% CI, 0.59 to 1.19). In the post hoc sensitivity analysis that accounted for missing data as described above, the odds ratio for unfavorable outcomes was 0.85 (95% CI, 0.59 to 1.23).

#### SECONDARY OUTCOMES

At 6 months, the GOSE ratings were similar in the two groups in the ordinal analysis (common odds ratio, 0.84; 95% CI, 0.59 to 1.18) (Table 2 and Fig. 2). Results for 30-day, 6-month, or 12-month mortality were similar in the two groups. A time-to-event analysis of length of stay, with follow-up data censored at death for patients who died in the ICU, showed that the median length of stay in the ICU was 10 days in both groups.

Additional cranial surgery within 2 weeks after randomization was performed in 28 of 192 patients (14.6%) in the craniotomy group and 13 of 188 (6.9%) in the decompressive craniectomy group (Table 2). In the craniotomy group, most additional operations (18 of 28) were decompressive craniectomies. Results for other secondary outcomes were similar in the two trial groups; full results are provided in Table 2 and Tables S7 through S15. The results of exploratory subgroup analyses are provided in Table S16.

#### SAFETY

Procedure-related adverse events occurred in 60 of 228 patients (26.3%) in the craniotomy group and in 57 of 222 patients (25.7%) in the decompressive craniectomy group ( $P=0.44$ ) (Table 3).

However, wound-related complications were reported in 4 patients in the craniotomy group and in 17 in the decompressive craniectomy group, and surgical-site infections were reported in 5 patients in the craniotomy group and in 10 in the decompressive craniectomy group. Noncranial adverse events (pulmonary, cardiac, renal, hepatobiliary, gastrointestinal, thrombotic, and miscellaneous) were reported in 113 of 228 patients (49.6%) in the craniotomy group and in 104 of 222 (46.8%) in the decompressive craniectomy group ( $P=0.28$ ).

#### DISCUSSION

In this trial involving adult patients with traumatic acute subdural hematomas warranting surgical evacuation, we found no significant difference across GOSE outcomes between the craniotomy group (bone flap replaced) and the decompressive craniectomy group (bone flap left out) at 12 months, and results for most secondary outcomes were similar in the two groups. Uniformly accepted criteria are lacking to predict the development of postoperative brain swelling and elevated intracranial pressure in this context and to inform the choice of craniotomy or decompressive craniectomy for evacuation of the hematoma. Systematic reviews of the literature have identified no randomized trials that address the issue that led to this trial; in nonrandomized studies, conclusions have been limited owing to confounding by indication, with more severely injured patients undergoing craniectomy more frequently than craniotomy.<sup>11,20</sup> Therefore, the role of a preemptive decompressive craniectomy in this context is not known and has been identified as a research priority.<sup>21</sup>

Although the present trial showed no significant difference in mortality or GOSE outcomes between the craniotomy group and the decompressive craniectomy group, additional cranial operations within 2 weeks after randomization were performed more frequently in the craniotomy group and most of them were decompressive craniectomies for brain swelling. However, patients in the decompressive craniectomy group had more wound-related complications and surgical-site infections. Even though disability and other outcomes were similar in the two groups, the trial may have practical implications. If the

**Table 2. Efficacy and Safety Outcomes.\***

Outcome	Craniotomy (N=228)	Decompressive Craniectomy (N=222)	Difference or Odds Ratio (95% CI)
<b>Primary outcome</b>			
GOSE rating at 12 mo — no./total no. (%)†‡			0.85 (0.60 to 1.18)§¶
Death	65/215 (30.2)	68/211 (32.2)	
Vegetative state	5/215 (2.3)	6/211 (2.8)	
Lower severe disability	38/215 (17.7)	41/211 (19.4)	
Upper severe disability	28/215 (13.0)	27/211 (12.8)	
Lower moderate disability	12/215 (5.6)	11/211 (5.2)	
Upper moderate disability	12/215 (5.6)	16/211 (7.6)	
Lower good recovery	17/215 (7.9)	13/211 (6.2)	
Upper good recovery	38/215 (17.7)	29/211 (13.7)	
<b>Secondary outcomes  </b>			
GOSE rating at 6 mo — no./total no. (%)†			0.84 (0.59 to 1.18)§
Death	63/206 (30.6)	57/201 (28.4)	
Vegetative state	7/206 (3.4)	14/201 (7.0)	
Lower severe disability	34/206 (16.5)	45/201 (22.4)	
Upper severe disability	28/206 (13.6)	29/201 (14.4)	
Lower moderate disability	16/206 (7.8)	9/201 (4.5)	
Upper moderate disability	17/206 (8.3)	16/201 (8.0)	
Lower good recovery	16/206 (7.8)	15/201 (7.5)	
Upper good recovery	25/206 (12.1)	16/201 (8.0)	
Death at 30 days — no./total no. (%)	48/225 (21.3)	44/220 (20.0)	1.09 (0.69 to 1.72)**
Further cranial surgery within 2 wk after randomization — no./total no. (%)††	28/192 (14.6)	13/188 (6.9)	7.60 (0.01 to 0.14)‡‡
EQ-5D-5L utility index score§§			
At discharge			
No. of patients evaluated	179	185	
Mean score	0.247	0.271	-0.024 (-0.098 to 0.049)
At 6 mo			
No. of patients evaluated	193	188	
Mean score	0.434	0.386	0.048 (-0.031 to 0.126)
At 12 mo			
No. of patients evaluated	197	199	
Mean score	0.455	0.397	0.058 (-0.024 to 0.141)

\* Percentages may not total 100 because of rounding.

† The eight outcome categories on the Extended Glasgow Outcome Scale (GOSE) are death, vegetative state (unable to obey commands), lower severe disability (dependent on others for care), upper severe disability (independent at home), lower moderate disability (independent at home and outside the home but with some physical or mental disability), upper moderate disability (independent at home and outside the home but with some physical or mental disability, with less disruption than lower moderate disability), lower good recovery (able to resume normal activities with some injury-related problems), and upper good recovery (no injury-related problems).

‡ Primary-outcome data were missing for 24 of 450 patients (5.3%). No imputation was undertaken for missing data. Shown is the common odds ratio.

§ P=0.32.

|| Because there was no prespecified plan for adjustment of the widths of confidence intervals for secondary outcomes, no definite conclusions can be drawn from these results.



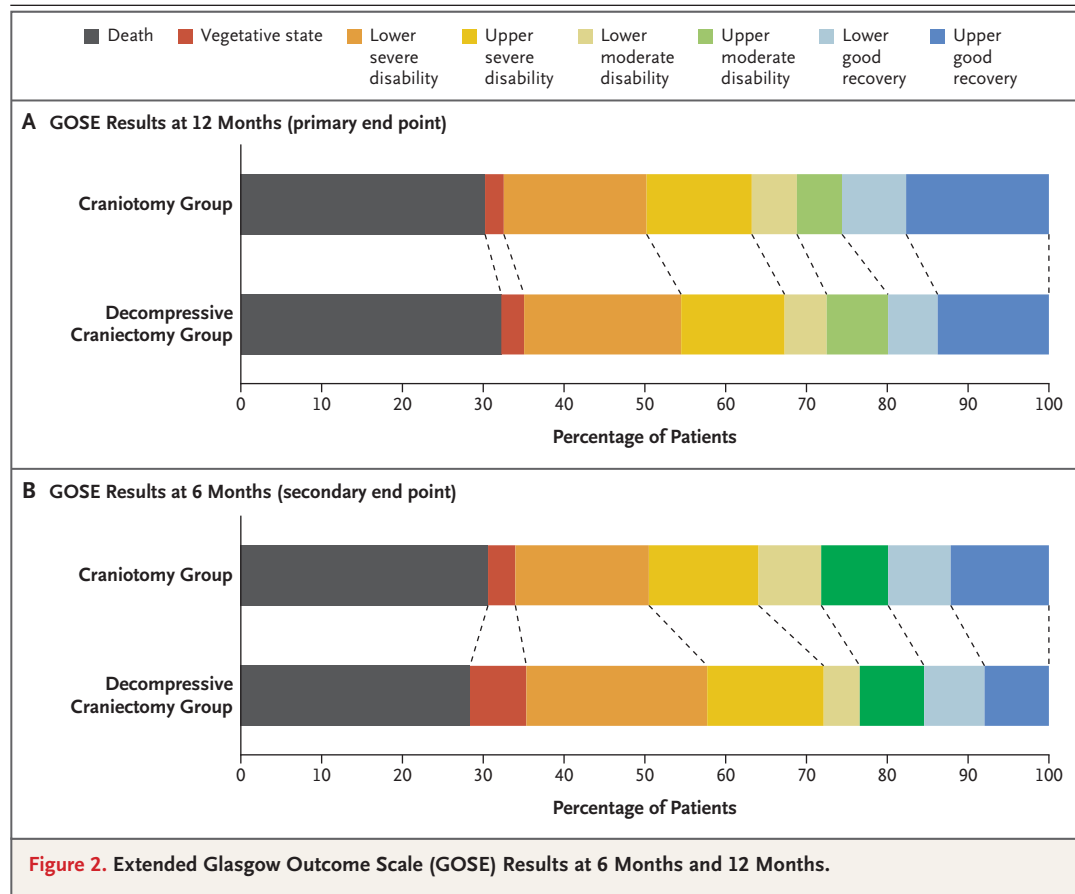
**Table 2. (Continued.)**

\*\* Shown is the odds ratio.

†† A total of 49 cranial operations within 2 weeks after randomization were reported in 41 patients across both groups; 5 of 28 patients in the craniotomy group and 2 of 13 patients in the decompressive craniectomy group had more than one cranial operation within 2 weeks after randomization. Of the 49 operations, 19 were decompressive craniectomies (39%); 18 of those occurred in the craniotomy group.

‡‡ Shown is the difference in percentage points.

§§ Responses on the EuroQol Group 5-Dimension 5-Level questionnaire (EQ-5D-5L) were converted into a utility index score with the use of the cross-walk algorithm; scores range from -0.594 (health state worse than death) to 1 (perfect health state), and patients who died were given a score of zero.



bone flap can be replaced without compression of the brain, surgeons may consider doing so, as opposed to performing a preemptive decompressive craniectomy. These findings may not be relevant for resource-limited or military settings, where preemptive craniectomy is often used owing to the absence of advanced ICU facilities for postoperative care.<sup>22,23</sup>

Our trial has limitations. First, the clinicians caring for the patients were aware of the trial-group assignments. However, outcome adjudica-

tion was performed by personnel who were unaware of the trial-group assignments. Second, outcome results were obtained by postal questionnaires or telephone interviews and may not reflect findings on clinical examination and personal interview. Third, 8.8% of the patients assigned to the craniotomy group underwent a decompressive craniectomy and 5.4% of those assigned to the decompressive craniectomy group underwent a craniotomy. This nonadherence to the trial-group assignment did not influ-

**Table 3. Adverse Events.**

Event	Craniotomy (N = 228)	Decompressive Craniectomy (N = 222)	Difference (95% CI)	P Value
	<i>no. of patients (%)</i>			
Noncranial adverse event*	113 (49.6)	104 (46.8)	2.70 (−0.07 to 0.12)	0.28
Procedure-related adverse event†	60 (26.3)	57 (25.7)	0.64 (−0.07 to 0.08)	0.44

\* A total of 270 noncranial adverse events were reported in 113 of 228 patients in the craniotomy group, whereas 289 adverse events were reported in 104 of 222 patients in the decompressive craniectomy group. There were no substantial between-group differences in the types of adverse events that occurred.

† A wound complication (including surgical-site infection) occurred in 9 of 228 patients (3.9%) in the craniotomy group and in 27 of 222 patients (12.2%) in the decompressive craniectomy group (P=0.001 by chi-square test).

ence the primary analysis, which was based on the modified intention-to-treat principle. Fourth, 36 patients (8.0%) who underwent randomization were not included in the final analysis owing to withdrawal of consent or loss to follow-up. However, the sample-size calculation for powering of the trial allowed for a loss to follow-up of up to 10%. Fifth, the trial did not formally examine other surgical techniques — such as floating or hinge craniotomy, larger-size craniectomies, removal of contusions, and cisternal opening and irrigation — that may have a role in this context.

In this trial involving adult patients undergoing evacuation of traumatic acute subdural hematoma, decompressive craniectomy and craniotomy yielded similar results with respect to overall outcomes at 12 months. Additional craniectomies were performed more frequently in the craniotomy group, but wound complications and

surgical-site infections occurred more frequently in the decompressive craniectomy group.

The views expressed are those of the authors and not necessarily those of the NHS, the National Institute for Health and Care Research (NIHR), or the Department of Health and Social Care.

Supported by the NIHR Health Technology Assessment Programme (project number 12/35/57). Dr. Hutchinson is supported by a research professorship and senior investigator award from the NIHR, the NIHR Cambridge Biomedical Research Centre, and the Royal College of Surgeons of England. Dr. Koliass is supported by a senior lectureship at the School of Clinical Medicine, University of Cambridge; the Wellcome Trust; and the Royal College of Surgeons of England. The RESCUE-ASDH trial is an “embedded study” linked with the CENTER-TBI project (<https://www.center-tbi.eu/>) of the European Brain Injury Consortium. CENTER-TBI was a large-scale collaborative project, supported by the FP7 Program of the European Union (grant number 602150).

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

A data sharing statement provided by the authors is available with the full text of this article at NEJM.org.

We thank the patients who participated in this trial, their families, and all the collaborating clinicians and research staff, and we thank the staff of the Cambridge Clinical Trials Unit for their support.

#### APPENDIX

The authors' full names and academic degrees are as follows: Peter J. Hutchinson, Ph.D., F.R.C.S. (SN), Hadie Adams, M.D., Midhun Mohan, M.R.E.S., M.R.C.S., Bhagavatula I. Devi, M.Ch., Christopher Uff, Ph.D., F.R.C.S. (SN), Shumaila Hasan, M.R.C.S., Harry Mee, M.R.C.P., Mark H. Wilson, Ph.D., F.R.C.S. (SN), Deepak K. Gupta, M.Ch., Ph.D., Diederik Bulters, F.R.C.S. (SN), Ardalan Zolnourian, M.R.C.S., Catherine J. McMahon, Ph.D., F.R.C.S. (SN), Matthew G. Stovell, M.R.C.S., Ph.D., Yahia Z. Al-Tamimi, F.R.C.S. (SN), Manoj K. Tewari, M.Ch., Manjul Tripathi, M.Ch., Simon Thomson, F.R.C.S. (SN), Edoardo Viaroli, M.D., Antonio Belli, F.R.C.S. (SN), Andrew T. King, F.R.C.S. (SN), Adel E. Helmy, Ph.D., F.R.C.S. (SN), Ivan S. Timofeev, Ph.D., F.R.C.S. (SN), Sarah Pyne, M.Sc., Dhaval P. Shukla, M.Ch., Dhananjaya I. Bhat, M.Ch., Andrew R. Maas, M.D., Ph.D., Franco Servadei, M.D., Geoffrey T. Manley, M.D., Ph.D., Garry Barton, Ph.D., Carole Turner, M.Sc., David K. Menon, F.Med.Sci., Barbara Gregson, Ph.D., and Angelos G. Koliass, Ph.D., F.R.C.S. (SN).

The authors' affiliations are as follows: the Division of Neurosurgery, Addenbrooke's Hospital (P.J.H., H.A., M.M., E.V., A.E.H., I.S.T., C.T., A.G.K.), the Department of Clinical Neurosciences (P.J.H., H.A., M.M., H.M., M.G.S., E.V., A.E.H., I.S.T., C.T., A.G.K.), and the Division of Anaesthesia (D.K.M.), University of Cambridge, and the Cambridge Clinical Trials Unit, Cambridge University Hospitals NHS Foundation Trust (C.T.), Cambridge, the Neurosurgery Department, Royal London Hospital (C.U., S.H.), and the Department of Neurosurgery, Imperial Neurotrauma Centre, Imperial College Academic Health Sciences Centre, St. Mary's Hospital (M.H.W.), London, Wessex Neurological Centre, University Hospitals Southampton NHS Foundation Trust, Southampton (D.B., A.Z.), the Department of Neurosurgery, Walton Centre NHS Foundation Trust, Liverpool (C.J.M., M.G.S.), the Department of Neurosurgery and the Academic Directorate of Neurosciences, Sheffield Teaching Hospital NHS Foundation Trust, Sheffield (Y.Z.A.-T.), the Department of Neurosurgery, Leeds General Infirmary, Leeds (S.T.), the Department of Neurosurgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham (A.B.), the Department of Neurosurgery, Manchester Centre for Clinical Neurosciences, Manchester (A.T.K.), Norwich Medical School, University of East Anglia, Norwich (S.P., G.B.), and the Neurosurgical Trials Group, Wolfson Re-

search Centre, Newcastle University, Newcastle upon Tyne (B.G.) — all in the United Kingdom; the Department of Neurosurgery, National Institute of Mental Health and Neurosciences (B.I.D., D.P.S.), and the Department of Neurosurgery, Aster RV Hospital (D.L.B.), Bangalore, the Department of Neurosurgery, All India Institute of Medical Sciences, New Delhi (D.K.G.), and the Department of Neurosurgery, Post Graduate Institute of Medical Education and Research, Chandigarh (M.K.T., M.T.) — all in India; the Department of Neurosurgery, University Hospital Antwerp, Edegem, Belgium (A.R.M.); Humanitas Research Hospital—IRCCS and Humanitas University, Rozzano, Milan (F.S.); and the University of California, San Francisco, San Francisco (G.T.M.).

## REFERENCES

- Kolias AG, Kirkpatrick PJ, Hutchinson PJ. Decompressive craniectomy: past, present and future. *Nat Rev Neurol* 2013;9:405-15.
- Hutchinson PJ, Kolias AG, Timofeev IS, et al. Trial of decompressive craniectomy for traumatic intracranial hypertension. *N Engl J Med* 2016;375:1119-30.
- Cooper DJ, Rosenfeld JV, Murray L, et al. Diffuse traumatic brain injury. *N Engl J Med* 2011;364:1493-502.
- Gantner D, Wieggers E, Bragge P, et al. Decompressive craniectomy practice following traumatic brain injury in comparison with randomized trials: harmonized, multi-center cohort studies in Europe, the United Kingdom, and Australia. *J Neurotrauma* 2022;39:860-9.
- Kramer AH, Deis N, Ruddell S, et al. Decompressive craniectomy in patients with traumatic brain injury: are the usual indications congruent with those evaluated in clinical trials? *Neurocrit Care* 2016;25:10-9.
- Steyerberg EW, Wieggers E, Sewalt C, et al. Case-mix, care pathways, and outcomes in patients with traumatic brain injury in CENTER-TBI: a European prospective, multicentre, longitudinal, cohort study. *Lancet Neurol* 2019;18:923-34.
- Clark D, Joannides A, Adeleye AO, et al. Casemix, management, and mortality of patients receiving emergency neurosurgery for traumatic brain injury in the Global Neurotrauma Outcomes Study: a prospective observational cohort study. *Lancet Neurol* 2022;21:438-49.
- Miller JD, Butterworth JF, Gudeman SK, et al. Further experience in the management of severe head injury. *J Neurosurg* 1981;54:289-99.
- Wilberger JE Jr, Harris M, Diamond DL. Acute subdural hematoma: morbidity, mortality, and operative timing. *J Neurosurg* 1991;74:212-8.
- Compagnone C, Murray GD, Teasdale GM, et al. The management of patients with intradural post-traumatic mass lesions: a multicenter survey of current approaches to surgical management in 729 patients coordinated by the European Brain Injury Consortium. *Neurosurgery* 2005;57:1183-92.
- Phan K, Moore JM, Griessenauer C, et al. Craniotomy versus decompressive craniectomy for acute subdural hematoma: systematic review and meta-analysis. *World Neurosurg* 2017;101:677.e2-685.e2.
- Henry J, Amoo M, Murphy A, O'Brien DP. Complications of cranioplasty following decompressive craniectomy for traumatic brain injury: systematic review and meta-analysis. *Acta Neurochir (Wien)* 2021;163:1423-35.
- Jennett B, Snoek J, Bond MR, Brooks N. Disability after severe head injury: observations on the use of the Glasgow Outcome Scale. *J Neurol Neurosurg Psychiatry* 1981;44:285-93.
- Wilson JT, Pettigrew LE, Teasdale GM. Structured interviews for the Glasgow Outcome Scale and the extended Glasgow Outcome Scale: guidelines for their use. *J Neurotrauma* 1998;15:573-85.
- van Hout B, Janssen MF, Feng Y-S, et al. Interim scoring for the EQ-5D-5L: mapping the EQ-5D-5L to EQ-5D-3L value sets. *Value Health* 2012;15:708-15.
- Herdman M, Gudex C, Lloyd A, et al. Development and preliminary testing of the new five-level version of EQ-5D (EQ-5D-5L). *Qual Life Res* 2011;20:1727-36.
- TBI-IMPACT. Therapy intensity level. May 2010 ([http://www.tbi-impact.org/cde/mod\\_templates/T\\_TIL9.1.pdf](http://www.tbi-impact.org/cde/mod_templates/T_TIL9.1.pdf)).
- Li LM, Kolias AG, Guilfoyle MR, et al. Outcome following evacuation of acute subdural haematomas: a comparison of craniotomy with decompressive craniectomy. *Acta Neurochir (Wien)* 2012;154:1555-61.
- Maas AIR, Steyerberg EW, Marmarou A, et al. IMPACT recommendations for improving the design and analysis of clinical trials in moderate to severe traumatic brain injury. *Neurotherapeutics* 2010;7:127-34.
- Rush B, Rousseau J, Sekhon MS, Griesdale DE. Craniotomy versus craniectomy for acute traumatic subdural hematoma in the United States: a national retrospective cohort analysis. *World Neurosurg* 2016;88:25-31.
- Bullock MR, Chesnut R, Ghajar J, et al. Surgical management of acute subdural hematomas. *Neurosurgery* 2006;58:Suppl:S16-S24.
- Bell RS, Mossop CM, Dirks MS, et al. Early decompressive craniectomy for severe penetrating and closed head injury during wartime. *Neurosurg Focus* 2010;28(5):E1.
- Charry JD, Rubiano AM, Nikas CV, et al. Results of early cranial decompression as an initial approach for damage control therapy in severe traumatic brain injury in a hospital with limited resources. *J Neurosci Rural Pract* 2016;7:7-12.

Copyright © 2023 Massachusetts Medical Society.